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SOME UNUSUAL ROCKS FROM MAINE[1]

EDSON S. BASTIN

I. PROWERSOSE FROM KNOX COUNTY

This unusual rock was collected by the writer in the summer of 1905 near Burkettville post-office in Knox County, Maine. It outcrops over a nearly circular area about 3½ to 4 miles across, which lies mainly in the town of Appleton, but extends a short distance west into the town of Washington, and north into the town of Liberty (Waldo County). It intrudes pelite schists and gneisses, and is itself cut by numerous dikes of pink aplitic granite. Bowlders of this rock had previously been observed 20 to 25 miles to the southeast, near the villages of Sprucehead and St. George.

In the field the rock was called a syenite-porphyry. The commonest phase is massive and shows numerous purplish-gray phenocrysts of feldspar in a rather fine, dark-green, even-grained matrix made up almost entirely of biotite and green hornblende (Fig. 1). The feldspar phenocrysts vary in length from ¼ to 1½ inches, 1 inch being about the normal length. A series of measurements on three hand-specimens showed that they constituted about 42 per cent. of the rock. Many are twinned according to the Carlsbad law, and some show zonal structure very perfectly brought out through concentric alternation of yellowish-gray with purplish-gray layers.

Microscopic study shows most of the feldspar to be a perthitic intergrowth or a somewhat irregular interpenetration of orthoclase or microcline, and albite. Microcline and orthoclase may or may not be present in the same crystal. In general, the potassic feldspar dominates greatly over the sodic, so that megascopically no albite twinning is visible in any of the phenocrysts. Some of the smaller phenocrysts are pure microcline, and a very few are pure orthoclase. Albite, not intergrown with the potash feldspars, occurs in a few places in aggregates of small grains associated with similar grains of orthoclase, and both grading into the perthitic intergrowths. It also occurs occasionally in small subangular grains inclosed in the large feldspar crystals. Most of the feldspar phenocrysts are full of inclusions. Some are dotted with subangular or rounded inclusions of quartz, and sometimes of orthoclase and albite, in grains averaging about $\frac{1}{10}$ of a millimeter in diameter; quartz thus included makes up perhaps 2 per cent. of the phenocrysts. Minute prisms of zircon are also of common occurrence. The most abundant inclusions appear hairlike under the low-power, but under the high-power are seen to consist of large numbers of minute, brownish, globular bodies arranged close together in perfectly straight lines. Some of these lines of globules are a millimeter in length. In a few cases the globules are seen to increase in length, so that they form a row of short prisms arranged end to end; these

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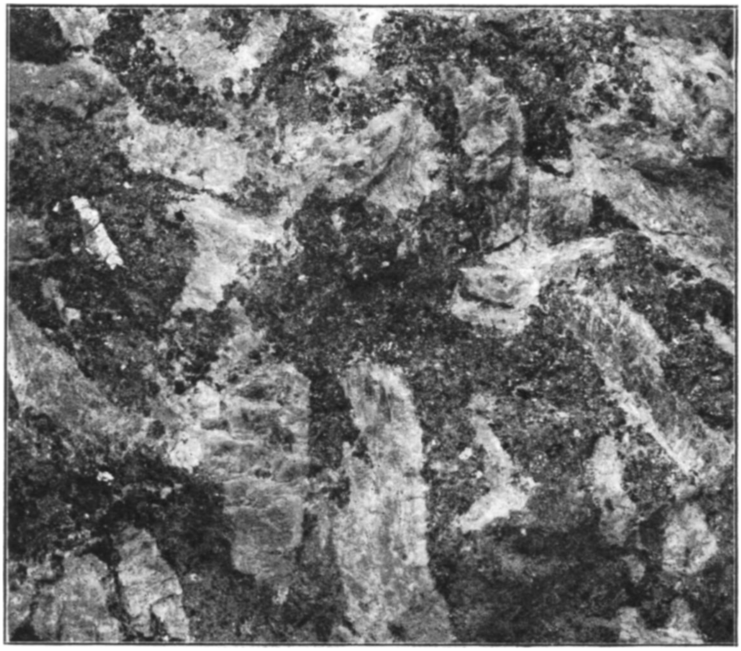

FIG. 1.—Prowersose from Knox County, Maine. Natural size.

become more and more elongate until we have a single long, needle-like crystal which resembles the rutile needles common in many quartzes. In certain of the feldspars these inclusions are arranged in two or three intersecting sets which, in some cases at least, parallel the cleavage planes, though in other parts of the feldspar they seem to have every conceivable orientation. Besides those mentioned above, there occur, scattered irregularly through the feldspar, a large number of minute, globular, or prismatic inclusions of indeterminate character.

The zonal structure observed in many of the feldspars is the result of the alternation of bands of only slightly different composition, rather than any considerable and progressive change in composition in passing from the center outward. The index of refraction in this case never rises above that of Canada balsam. Some bands are orthoclase, while others are microcline, and slight variations in composition are also indicated by slight differences in the double refraction and in the extinction angles. Inclusions are very much more abundant in some of the bands than in others, and it is those bands which contain the abundant inclusions that are dark-colored megascopically. This suggests that the peculiar purplish-gray color of certain parts of the feldspar may be due largely, if not wholly, to the inclusions.

The groundmass, when examined microscopically, shows the minerals indicated in the following table:

	Proportions in Groundmass	Proportions in Whole Rock
Biotite	55.5%	29.0%
Hornblende	32.6	19.0
Titanite	6.3	3.5
Apatite	5.0	3.0
Quartz	3.2	3.0
Titaniferous Magnetite	1.6	1.0
Feldspar	0.7	41.5*
Total	99.9	100.0

*An estimated amount of 1 per cent. of quartz occurs as inclusions in the feldspars.

Brown biotite, the most abundant of the ferromagnesian constituents, occurs in plates of various sizes up to 2^{mm} across. All are perfectly fresh. Within the larger plates inclusions of titanite, often forming a border about ilmenite or titaniferous magnetite, are abundant. Some zircon and numerous apatite prisms are also inclosed.

The hornblende individuals seldom exceed $\frac{1}{2}$ $^{\mathrm{mm}}$ in diameter, but are usually grouped in aggregates which may be 2 to 3 $^{\mathrm{mm}}$ across. The color is light green, and the pleochroism is not marked. The aggregates inclose some biotite, some titanite, and abundant prisms of apatite.

Titanite occurs abundantly in small grains, but larger aggregates are usually associated with a mineral showing the optical properties of magnetite. This mineral is probably ilmenite or titaniferous magnetite. If forms a core surrounded by rather an even border of titanite, or else occurs in small irregular grains scattered through the central portion of the titanite aggregate. Some of these titanite and titaniferous magnetite masses are over 1$\frac{1}{2}$ $^{\mathrm{mm}}$ in diameter. This association suggests that the titanite is a decomposition product from the titaniferous magnetite. This decomposition is somewhat remarkable in view of the exceedingly fresh state of the hornblende and the biotite; but it seems improbable that the titanite and titaniferous magnetite are in parallel growth, or that the hornblende and biotite owe their fresh appearance to recrystallization.

Apatite is very abundant in short prisms averaging about $\frac{1}{10}$ $^{\mathrm{mm}}$ in diameter. These are inclosed by all the other constituents of the rock, even by the titaniferous magnetite.

Quartz occurs, mainly about the borders of the feldspar phenocrysts, in small grains which are usually aggregated.

Feldspar is present only rarely in the groundmass, and is then usually close to the phenocrysts. It is microcline or orthoclase.

In some of the feldspar phenocrysts we find inclosures which have the same mineral composition as the groundmass. Upon careful examination, these are seen to occur along lines of healed fracture. When several such inclosures occur in the same phenocryst, they seem to be connected by an irregular band of feldspar differing slightly in appearance from the rest of the phenocryst. This difference may consist (1) in a lesser abundance of minute inclusions,

(2) in a slight difference in the proportions of the two feldspars in the microperthite, or (3) in a slight difference in the form of the bands, where the feldspar is microperthite. Along this zone we may also find small, scattered crystals of hornblende or of biotite. This phenomenon indicates a fracturing of the phenocrysts before the groundmass was completely crystallized, the introduction of portions of the groundmass into the fracture, and the healing of the fracture, probably by crystallization out of the mother-liquor.

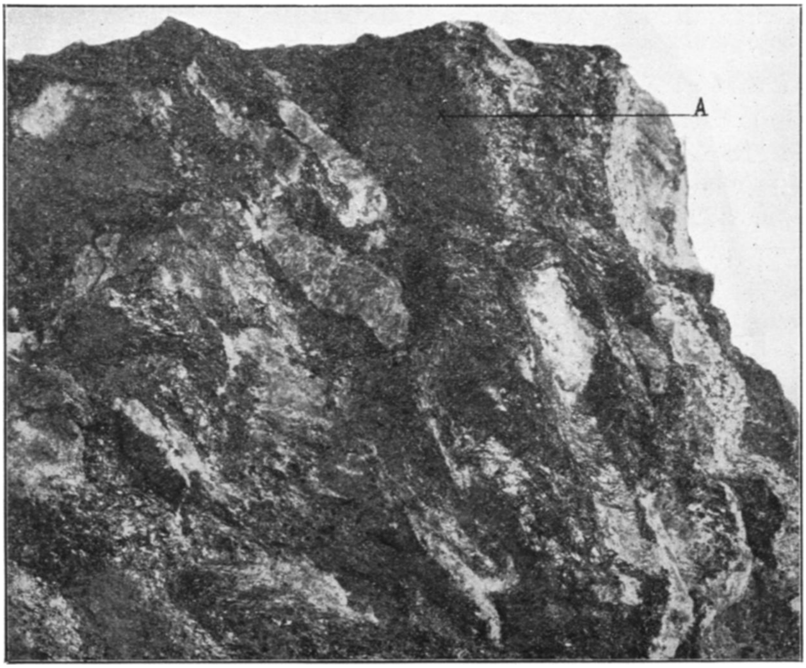

FIG. 2.—Sheared specimens of Prowersose from Knox County, Maine. Nearly natural size. Face slightly inclined to the schistosity. A=one of the mica-coated phenocrysts.

The feldspar phenocrysts seem to have been developed early in the crystallization of the rock, though antedated by the small quartzes and feldspars which they inclose. It is possible that they were fully grown before crystallization of the groundmass commenced. None of the slides show clearly that the feldspars inclosed portions of the groundmass in any other way than that described above. Of the minerals of the groundmass, apatite seems to have been the first to crystallize, followed by titaniferous magnetite, biotite, quartz, and hornblende. In only a few instances is the hornblende inclosed in biotite, but the reverse relation is very common.

Near the border of the area the porphyry has, in many places, been considerably sheared. The feldspars for the most part remain intact, though showing some fracturing and bending under the microscope. They have become coated, however, with a "skin" of secondary biotite which adheres even after they have weathered out from their matrix (Fig. 2). Except for this development of mica, the sheared rock differs but little in microscopic appearance from the unsheared.

The chemical analysis, and the classification of this rock according to the quantitative system, are given in the tables on the opposite page.

According to Washington's[1] table of rock analyses, the only other known rock falling in this subrang is one collected by G. K. Gilbert from Two Buttes, Prowers County, Colo., and briefly described by Whitman Cross.[2] This is a laccolitic rock, and has as its chief constituents diopside, alkali feldspar, considerable biotite magnetite, and olivine. The ferromagnesian minerals predominate.

These rocks are peculiar in their high alkali content and in the preponderance of potash over soda. The only other highly alkaline rocks (perkalkalic or domalkalic) of this class which show a corresponding preponderance of potash (perpotassic or dopotassic) are wyomingose, madupose, and orendose from the Leucite Hills of Wyoming, chotose from the Bearpaw Mountains of Montana, and albanose from the Alban Hills of Italy. All of these rocks show leucite in the mode, and in all except orendose it is present also in the norm. In orendose the high potash content is indicated by the presence of potassium metasilicate in the norm. In prower-

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[1] H. S. Washington, "Chemical Analyses of Igneous Rocks," *Professional Paper No. 14*, U. S. Geological Survey, p. 313.

[2] See *Bulletin No.* 228, *U. S.* Geological Survey, p. 186.

	Prowersose from* Knox Co., Maine	Prowersose from† Two Buttes, Prowers County, Colo.
SiO_2	52.26 0.871	50.41 0.840
Al_2O_3	10.63 0.104	12.27 0.120
Fe_2O_3	2.47 0.015	5.71 0.035
FeO	5.45 0.076	3.06 0.043
MgO	9.32 0.223	8.69 0.217
CaO	5.62 0.100	7.08 0.127
Na_2O	1.60 0.026	0.97 0.016
K_2O	5.99 0.064	7.53 0.080
H_2O+	1.97	1.80
H_2O-	0.98	0.46
TiO_2	1.92 0.024	1.47 0.018
P_2O_5	0.98 0.007	0.46 0.003
MnO	0.12 0.002	0.15 0.002
ZrO	0.08 0.001	....
CO_2	0.75	....
BaO & SrO	....	0.29
V_2O_3 & NiO	....	0.07
Total	100.14	100.42

*Analysis by George Steiger, Laboratory of U. S. Geological Survey

†Analysis by W. F. Hillebrand, Laboratory of U. S. Geological Survey.

NORM OF PROWERSOSE FROM KNOX COUNTY, MAINE, CALCULATED FROM THE ANALYSIS

Orthoclase	35.58%
Albite	13.62
Anorthite	3.89
Diopside	13.90
Olivine	4.91
Hypersthene	15.04
Magnetite	3.48
Ilmenite	3.65
Apatite	2.35
Zircon	0.18
Water	2.95
Carbon dioxide	0.75
Total	100.27

Class, $\frac{\text{Sal.}}{\text{Fem.}} = \frac{53.09}{43.51} = <\frac{5}{3}>\frac{3}{5} = \text{III}$, Salfemane.

Order, $\frac{Q}{F} = \frac{O}{53.09} = <\frac{1}{7} = 5$, Gallare.

Rang, $\frac{K_2O+Na_2O}{CaO} = \frac{90}{14} < \frac{7}{1} > \frac{5}{3} = 2$, domalkalic, Kilauase.

Subrang, $\frac{K_2O}{Na_2O} = \frac{64}{26} < \frac{7}{1} > \frac{5}{3} = 2$, dopotassic, *Prowersose*.

sose the only potash minerals in the mode are biotite, microcline, and orthoclase, while in the norm only orthoclase is present.

II. ALBITE-PYROXENE-SYENITE

These rocks form part of a series of greenstones which have a more or less scattered distribution over an area of about 250 square miles among the islands of Penobscot Bay. The largest continuous area is on North Haven, where they occupy all but the extreme southern parts of the island. From North Haven they extend northwestward to Islesboro and the islands south of it; eastward they extend to the western part of Deer Isle; to the north they reach the mainland in the vicinity of South Brooksville.

The greenstone series consists of diabases, basic trachytes, and albite-pyroxene-syenites, which in very many places show the characters of surface volcanics in the occurrence of tuffs, breccias, and amygdaloidal phases, and in the development of columnar parting and "bolster" or "pillow" structure. Most of these rocks show considerable alteration, but enough moderately fresh specimens occur to place their original character beyond doubt.

It is difficult to estimate the exact proportion which the albite-pyroxene-syenite bears to the trachytes and diabases, but it probably constitutes nearly, if not quite, one-half of the greenstone series. Its normal phase is massive, and it is usually associated with the other greenstones and with the neighboring acid volcanics in the form of dikes and sills. In a few cases, as will be described later, it shows the characteristics of a surface volcanic. With most of the other rocks of this region, it has been affected by regional metamorphism, and in numerous localities a slight schistosity has been developed.

Intrusive phases.—The commonest type of albite-pyroxene syenite is a massive to feebly schistose rock, usually dark green in color, or showing a mottling of light and dark green, the light-green portions representing somewhat altered feldspar areas, and the dark-green the ferromagnesian constituents; in some of the more feldspathic phases the feldspars are almost pure white.

Upon microscopic examination, the texture is usually found to be poikilitic. In some specimens this texture is rendered irregular by the great variations in the size of the feldspar individuals, while in others it has been obscured or destroyed in the development of a schistose structure or in the weathering. The feldspars are striated and usually form rather short prisms, most of which range from ½ to 1½^{mm} in length; in many of the slides they are remarkably fresh. They are shown to be albite by their low extinction angles, and by the index of refraction, which is uniformly equal to, or less than, Canada balsam. The pyroxene, which normally forms a poikilitic matrix for the feldspar laths, is pale pinkish-yellow in color, with a hardly noticeable pleochroism, and shows extinction angles ranging up to 45, but usually under 40°. These angles are found in both augite and diopside, but the fact that the angles never exceeded 45° in the half-dozen or so slides studied, as well as certain considerations as to chemical composition to be brought out later, points to the non-aluminous diopside rather than to an aluminous pyroxene. Magnetite is the only other original constituent which plays an important rôle; it occurs in irregular grains, which sometimes assume skeleton forms, and may then partially inclose feldspar crystals.

Near the head of Southern Harbor, on the island of North Haven, the syenite is peculiar in the possession of scattered feldspar phenocrysts which are occasionally ½ inch in length. Relatively fresh representatives of the common massive type are found on Hardhead Island and at the southern end of Spruce Head Island.

Exrustive phases.—Amygdaloidal phases of the syenite were found on the southern end of Bare Island. A part of Mark Island and the greater portion of Beach Island are occupied by a phase of the greenstones characterized by the development of very ragged surfaces on weathering, and by the possession often of a purplish tint which is not characteristic of the greenstones elsewhere. In certain places the weathering reveals a distinctly tuffaceous character. In the field these were looked upon as flows and tuffs, and this is borne out by the microscopic examination, which shows them to be a very fine-grained phase of the albite-pyroxene-syenite series. The rock shows a diabasic texture with laths of albite, varying considerably in size, but mainly minute; between them is chlorite, epidote in small grains, and somewhat altered magnetite.

Weathering and shearing effects.—Even those occurrences of the syenite which, in the hand-specimen, appear massive and very fresh, show under the microscope traces of dynamic action and of very considerable weathering. Distinctly, though not highly, schistose phases are even commoner than the massive phases, and are usually much more altered mineralogically. In a few of the less schistose phases considerable pyroxene still remains, but even here some of this mineral has decomposed with the development of hornblende. In the more schistose phases the femic constituents are green hornblende, fibrous actinolite, and chlorite; in some only chlorite remains. Albite has resisted decomposition much longer than a calcic feldspar would have done under the same conditions. The laths often show fracturing, a pulling apart of the fragments, and their rotation, partial or complete, so that their longer axes lie in the plane of the schistosity. The rotation of the feldspars contributes to the development of the schistose structure, which, however, is due primarily to the distribution of the chlorite in long irregular bands, to some parallelism among the shreds of fibrous hornblende, and to the distribution of secondary epidote grains in irregular aggregates which are elongate palallel to the bands of chlorite. Occasionally some muscovite is developed and aids in defining the schistosity. Magnetite is usually largely altered to titanite or leucoxene. Zoisite, calcite, apatite, biotite, and chloritoid minerals are minor secondary constituents which are sometimes present. Very rarely serpentine has been abundantly developed, as in the intrusive mass which forms the 80-foot hill just east of the steamboat landing at Eggemoggin on Little Deer Isle.

So far as the writer's knowledge goes, all of the pyroxene-syenites thus far described which have contained albite have also contained nephelite or some calcic feldspar, and in most cases the albite has been a very subordinate constituent. The rock here described is unusual in the abundant association of the non-calcic feldspar, albite, with the calcic mineral, pyroxene. In the absence of sufficient material from localities where the rock was freshest, no chemical analyses could be made, and without such it would be unsafe to attempt an explanation of this association. It may be suggested, however, that the explanation may lie in a deficiency of alumina.

The soda, having a stronger affinity for alumina than the calcium, would appropriate it all in the production of albite, while the calcium would be forced to combine with the iron and magnesia in the formation of diopside.

III. A NEW OCCURRENCE OF CORTLANDITE

In 1886 G. H. Williams[1] described certain peridotites from the Cortland series near Stony Point, N. Y., which were peculiar mainly in the development of large hornblende crystals which served as a poikilitic matrix for olivine grains. It was in the description of these rocks that the term "poikilitic" was first applied. The hornblende crystals occasionally reach a diameter of 4 inches, and frequently show "schillerization." The olivine is usually very fresh. Besides these two constituents, some hypersthene, augite, biotite, and magnetite are usually present; feldspar is sometimes an accessory, but is never important. For this rock Williams[2] proposed the name "Cortlandite."

Professor B. K. Emerson[3] has described a peridotite from Belchertown, Hampshire County, Mass., which exhibits most of the characters of William's rock and to which he has applied the same name, and Williams[1] has published an analysis of a somewhat altered occurrence from Howard County, Md. The analyses of these rocks place them in Class IV Dofemane, Order 1 Perpolic, and Rang 1 Permirlic, of the quantitative system.

The rock to be described below occurs near the village of Penobscot in Hancock County, Maine, in the Bluehill Quadrangle. It forms a single outcrop, hardly 30 feet in length and breadth, located about ½ mile east of Pierce Pond. The ledge rises above its surroundings in such a manner as to resemble a huge half-buried bowlder, but the rock is undoubtedly in place and owes its prominence merely to a superior resistance to glacial erosion. Post-glacial weathering has been very considerable, and a red soil containing scattered hornblende crystals is the result; on the weathered faces the large hornblendes, some of them $2\frac{1}{2}$ inches across, stand out so as to give a knotty or warty appearance. The rock is exceedingly tough and resistant under the hammer.

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[1] G. H. Williams, "The Peridotites of the 'Cortland Series' on the Hudson River near Peekskill, N. Y.," *American Journal of Science*, Third Series, Vol. XXXI (1886), pp. 26–41.

[2] *Ibid.*, p. 30.

[3] B. K. Emerson, *Monograph XXIX*, U. S. Geological Survey, 1898, pp. 346, 347.

The megascopic appearance is very similar to that described by Williams for the type locality. The hand-specimen shows a dark-green to almost black rock, with hornblendes ranging from $\frac{1}{2}$ to $2\frac{1}{2}$ inches in diameter; when held at the proper angle, these reflect the light as units, but show numerous dull, irregular inclusions from $\frac{1}{32}$ to $\frac{1}{8}$ of an inch in diameter, which under the microscope prove to be olivine or its alteration product, serpentine, with an occasional crystal of pyroxene. Light-brown biotite is the only other mineral recognizable megascopically; it occurs between the hornblendes and is quite abundant.

Under the microscope the rock is seen to be only slightly altered. The hornblende is mainly massive, but is occasionally fibrous about the edges of the grains, where some alteration has taken place. The color ranges from light green to light brown; the pleochroism is noticeable, but not very strong, $\mathfrak{a}$ = light yellow, $\mathfrak{b}$ = light green, $\mathfrak{c}$ = light green to light brown. Inclusions of magnetite are abundant in the hornblende and vary greatly in size. The majority are quite irregular in outline, but show a tendency toward elongation in the direction of the hornblende cleavage and toward the possession of straight boundaries in this direction. In some of the hornblende crystals inclusions of magnetite and also of pyrite assume minute needlelike or platelike forms, usually elongate parallel to the cleavage planes, but in some cases occurring in as many as three sets, inclined at widely divergent angles. This latter type of inclusions gives to the mineral, when viewed in reflected light, the peculiar metallic sheen which has been described by Judd and others, and has been termed "schillerization."

Olivine ranks next to hornblende in abundance and occurs in grains of more or less rounded outline, usually inclosed by the hornblende; they vary considerably in size. The characteristic irregular fracturing is present, and a few grains show slight serpentinization along the cracks. The serpentine is usually light-colored and appears gray between crossed nicols; occasionally the yellowish-green variety is developed. The olivine contains numerous magnetite inclusions, usually very irregular in form, and distributed principally along the cracks; some of the smaller ones show dendritic forms. All are probably of secondary origin.

Hypersthene occurs in irregularly bounded grains. Pleochroism strong, $\mathfrak{a}$=pale salmon-pink, $\mathfrak{b}$=pale yellow, $\mathfrak{c}$=pale green. It occasionally incloses both olivine and biotite. In a few places it shows slight alteration to hornblende.

Biotite is abundant and quite strongly pleochroic, colorless to pale yellow parallel to $\mathfrak{a}$, yellowish to light brown parallel to $\mathfrak{b}$ or $\mathfrak{c}$; it seems to be in small part a product of hornblende alteration.

A micaceous mineral showing only feeble pleochroism and interference colors never above yellow of the first order is probably intermediate in character between chlinochlore and pennine. It appears to be uniaxial and optically positive, with the slow direction parallel to the micaceous cleavage (i. e., perpendicular to $\mathfrak{c}$). The pleochroism is light green for rays vibrating parallel to the base, and colorless for rays at right angles to this.

Magnetite and olivine were the first minerals to crystallize, followed by hornblende, hypersthene, and biotite, the last three being about contemporaneous. The elongation of many of the magnetite inclusions parallel to the cleavage planes of the inclosing hornblende, shows either some secondary magnetite crystallization, or else a partially contemporaneous crystallization of hornblende and magnetite.

Megascopically, the Maine rock differs from the type rock of Stony Point, mainly in showing a much larger amount of biotite. Microscopically, the same difference is apparent, and it is also seen that the colors of the hornblende are much paler in the Maine specimen; in the Stony Point rock this mineral is a dark reddish brown. Some of the Stony Point specimens show feldspar as a subordinate constituent, but here it is wholly absent. The relative proportions between hornblende and olivine seem to be about the same in the two rocks. No chemical analysis was made of the Maine rock, but it is probable that it will fall within the same order as those already analyzed.

The geologic age of the rock here described is uncertain, because the actual contacts are not exposed. It is associated with a border zone of diorite and gabbro surrounding, and practically contemporaneous with, a large granite mass of probable Devonian age. This association, however, may be accidental, and the Cortlandite may be a considerably later intrusion.

IV. PORPHYRITIC GRANITE FROM SOMERSET COUNTY

The specimen here described was collected by Dr. George Otis Smith in the course of a reconnaissance trip in the summer of 1905, and is worthy of brief notice because of its unusually coarse porphyritic character. Bowlders of this rock are common in Somerset County, and in going up the Carrabassett valley they become more and more plentiful, the rock being found in place in Highland Plantation. Here it forms the divide between Dead River and Carrabassett River, both tributaries of the Kennebec. Where crossed by the county road it shows tabular feldspars 3 to 5 inches in length, and is exposed for several miles. The porphyritic granite does not extend into the adjacent townships to the east and west, and that seen both to the north and south of this locality is more of the normal type. The coarsely porphyritic rock seems to be characteristic of an area a few miles square, which does not, however, represent a peripheral zone, but is more probably a separate intrusive mass in a region quite thoroughly intruded with granite.

The specimen examined by the writer came from well within this area. It shows a number of phenocrysts of feldspar, tabular parallel to the *b* pinnacoid, and lying in approximately parallel positions. The largest of these is 7 inches long, 3 inches wide, and ½ to ¾ of an inch thick. In most of the crystals a very pronounced zonal structure is shown on these side pinnacoid faces, and is seen to be due partly to the greater abundance of muscovite along certain layers, and partly to slight differences in tint which probably correspond to slight variations in composition. A microscopic examination of material from the center and from various points on the periphery of the crystal, using Wright's[1] adaptation of Schroeder's method, showed that there was no considerable or progressive change in composition from the center outward. The feldspar throughout is microcline and orthoclase, occasionally perthitically intergrown with small amounts of albite. The groundmass is a medium-grained association of quartz and potash feldspar, in nearly equal amounts. With these are associated abundant brown biotite and small amounts of muscovite. The texture is granitic.

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[1] F. E. Wright, *American Journal of Science*, Vol. XVII (1904), pp. 385–87.